

Design and Evaluation of Ankle Reconstruction

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ABSTRACT

Ankle reconstruction is a fairly new concept and is one of the popular treatment for ankle fractures and arthritis. Ankle reconstruction aims to offer a successful alternative to arthrodesis, the existing mainstay and gold standard surgical procedure for disabling ankle arthritis. The surgeon fits the talus bone of the upper foot and the tibia bone at the end of the lower leg with metal components made of cobalt-chromium alloy with pure titanium where they come in contact with bone. This project focuses on modelling and 3D printing of a prosthetic talocrural joint. The standard sizes of tibia which is the longer base of lower leg and talus being lower part of the ankle joint are observed and modelled accordingly by using CATIA with standard dimensions. The prototype is made with PLA plastic using an FDM (Fused Deposition Modelling) 3D printer. The analysis test carried on ANSYS by applying human weight on the tibial surface and physical tests are conducted on universal testing machine. The compressing force is applied on the prototype and observed till failure. Results obtained are compared for static position of the foot of both analytical and physical outcomes.

KEYWORDS: Ankle, Arthrodesis, Talocrural joint, PLA Plastic, Prototype, FDM, 3D printer

INTRODUCTION

Introduction to 3D Printing Technology

The term additive manufacturing (AM) includes many technologies including subsets like 3-D printing, rapid prototyping (RP), direct digital manufacturing (DDM), layered manufacturing and additive fabrication. Additive manufacturing, the industrial version of 3-D printing is already used to make some niche items in many industries. The terms 3-D printing and additive manufacturing have become interchangeable. The term additive manufacturing refers to the technology or additive process of depositing successive thin layers of material upon each other, producing a final three dimensional product. Each layer is approximately 0.001 to 0.1 inches in thickness. A wide variety of materials can be utilized, namely plastics, resins, rubbers, ceramics, glass, concretes, and metals. Rapid prototyping refers to the application of the technology. This was the first application for AM, which assisted in the increase of time-to-market and innovation. It can be referred to as the process of quickly creating a model/prototype of a part or finished good. This part or finished good will be further tested and scrutinized before mass production occurs. Most commercial 3-D printers have similar functionality. The printer uses a computer-aided design (CAD) to translate the design into a three-dimensional object. The design is then sliced into several two-dimensional plans, which instruct the 3-D printer where to deposit the layers of material. In the past few years, many companies have embraced AM technologies and are beginning to enjoy real business benefits from the investment.

Three-dimensional printing, also known as additive manufacturing (AM) or rapid prototyping, has been around for decades. The first working 3-D printer was created in 1984 by Charles W. Hull of 3-D Systems Corp. He named the machine stereolithography apparatus. The technology was very expensive and not feasible for the general market in the early days. As we moved into the 21st century, however, costs drastically decreased, allowing 3-D printers to find their stereolithography apparatus. The technology was very expensive and not feasible for the general market in the early days. As we moved into the 21st century, however, costs drastically decreased, allowing 3-D printers to find their usage. The 3-D printer works in a very similar way to the standard inkjet printer, however, instead of printing layers of ink on paper, a 3D printer uses materials to build a three-dimensional object.

There are different ways by which the varied models of 3D printers operate, they're all based on a simple premise. As the term 'additive printing' suggests, 3D printers work by "adding" layers of print material together to create an object. Converting a software-based design into distinct 2D layers or slices, which are "printed" and bonded to each other in order to create a 3D product is the primary method of operation of any 3D printer.

The overall workflow of any 3D printer is oriented towards achieving the goal of converting a 3D design

How to cite this paper: A. Kranthi Kumar | B. Sai Krishna | B. Sai Ram | Mr. P. Naresh "Design and Evaluation of Ankle Reconstruction"

Published in International Journal of Trend in Scientific Research and Development (ijtsrd), ISSN: 2456-6470, Volume-4 | Issue-3, April 2020, pp.212-214, URL: www.ijtsrd.com/papers/ijtsrd30327.pdf



IJTSRD30327

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created using software into a hardcopy version. Depending on the type of printer and the object being printed, the material used can be liquid, powder, paper, metal or even food based. The printer uses the cross-sections of the object to create the final item. Since almost every object can be physically broken down into layers, the reverse process of joining together the layers is made simple by the printer.

LITERATURE SURVEY

John Fisher et al studied that the ankle joint is prone to post traumatic arthritis, when the ordinary treatment fail, two kinds of operations can be performed namely ankle arthrodesis (AA) and total ankle replacement (TAR). The TARs can be further divided into two categories, semi constrained two component design and unconstrained three component design. The two component designs provide greater stability but at the increased risk of higher shear forces at the tibial-bone interface. The unconstrained design reduces the shear forces but the chance of dislocation is more. In their study five Zenith (Corin Group PLC, Cirencester, UK) unconstrained TARs were tested. The Zenith comprised of three components, a flat tibial component, a dual condyle talar and a mobile bearing insert which conformed to both of these surfaces. The tibial and talar components consisted of bulk titanium coated with ceramic like Titanium Nitride (TiN). A mid-range implant size was selected as this was the most frequently implanted. These were paired with the thinnest polyethylene insert with a minimum thickness of 5 mm. The wear of a TAR was assessed through several kinematic conditions. During the initial unidirectional input for stage one the wear rate was $1.2 \pm 0.6 \text{ mm}^3/\text{Mc}$. The addition of 11° rotation and 9 mm of AP displacement in stage two resulted in a statistically significant increase ($p=0.000$) in the wear rate to $25.8 \pm 3.1 \text{ mm}^3/\text{Mc}$. At the end of this stage, two tibial components showed severe coating damage and were replaced with new tibial components for the subsequent stages [1].

Henry Wang et al explained the effects of replacement of ankle joint on the mechanics during walking, ankle arthritis results in malfunctioning of the ankle joint causing disabilities. The total ankle replacement (TAR) is used to treat end stage arthritis to eliminate joint pain, the Salto Talaris Anatomic Ankle (STAA) developed by the Tornier Inc characterized by the unconstrained tibial and talar components, helps patients to quickly gain ankle function and strength. Five patients who developed unilateral ankle osteoarthritis due to severe ankle joint injuries volunteered in the study. Standard surgical procedure for installing fixed bearing TARs was performed. Patients clinical and functional outcomes were assessed by an experienced physical therapist via the American Orthopaedic Foot and Ankle Society (AOFAS) hindfoot score system. Three-dimensional (3D) trajectories of reflective markers placed on the body were captured during testing trials using a 12-camera (MX 40) motion capture system. VICON Workstation (Version 5.2.4) was used to generate gait temporospatial parameters such as walking speed, stride length, stance time, and double support. In addition, ankle joint mechanics including maximal dorsiflexion, maximal plantar flexion, and joint excursion (joint range of motion from peak dorsiflexion to peak plantarflexion during stance of gait), peak ankle joint moment, and peak ankle joint power were analyzed for both pre- and post-TAR surgeries. Statistical analysis was

performed using SPSS software. The AOFAS hindfoot score at 3 months of post-surgery (74 ± 10) was significantly greater than that of the pre-surgery condition (48 ± 17) ($p = 0.0001$) [2].

John E Femino et al, elaborates about the factors to be considered before performing total ankle replacement (TAR), they are 1) limb and ankle alignment, 2) bony and ligamentous anatomy of the ankle joint, 3) ankle motion which occurs in the sagittal, coronal, and transverse planes and 4) both talocrural and subtalar joint contributions to motion in these three planes. The TAR is performed on patients older than 50 years with end-stage ankle arthrosis, non-obese and with low physical demands. Another factor that needs to be taken into account is the presence of degenerative changes in other joints, such as the subtalar, midtarsal, knee, hip, and the contralateral ankle. These patients seem to benefit more from TAR than from arthrodesis. The first-generation ankle replacements were found to be poor and it was recommended their use be discontinued. With newer designs, encouraging results have been reported. Studies on long-term prosthetic survival rates (>10 years follow-up) of TAR have mainly been reported by inventors of the different prostheses. TAR should no longer be considered inferior to ankle fusion or as an experimental procedure. Surgeons should remember that TAR is not for every patient and that the appropriate indication, based on the evidence available, is fundamental to obtaining durable and predictable outcomes [3].

Beat Hintermann et al, studied the ankle osteoarthritis (OA), it is characterized by a progressing loss of normal structure and function of the articular cartilage, ending in a complete anatomical and functional joint destruction. The ankle OA is to be seen in the high incidence of fractures about the ankle in the past decades. The fractures of the tibial shaft, the distal tibia, the malleoli and the talus could well be the origin of a post-traumatic OA as chronic malalignment, chondral joint damage, or chronic instability. Total ankle replacement (TAR) is considered as a valuable treatment option in patients with end-stage ankle OA. TAR has a relatively short history compared with total replacement of the hip and knee joints. To solve the problem of early discovered designs the HINTEGRA ankle was developed as a new ankle prosthesis concept. The main innovation was a flat resurfacing area of an anatomically shaped tibial component to use the whole resection area of tibial metaphysis for bony support and to avoid any stress shielding. The talar component is anatomically shaped, with a shorter radius on medial side. HINTEGRA ankle design has evidenced some problems of mid- to long-term stabilities of components, improvements were achieved by adding pegs to talar component and Titanium fluid on porous coat. This new three-component prosthesis requires minimal bone resection, retains the entire cortical rim of the distal tibia, has enlarged components, and has anatomic-shaped surfaces [4].

T. M Chu et al explained the three dimensional finite element stress analysis of the polypropylene, ankle-foot orthosis, an injury or disease can result in abnormal motion of the ankle joint, the drop foot problem which causes the uncontrolled planter flexion. The ankle foot orthoses(AFO) are recommended to solve the drop foot, currently the orthoses are manufactured from the polymers like poly

propelyne, they are based on the beam equation and small deflection theory. A 3D finite element model of the AFO was developed along with foot using PATRAN and analyzed using ADINA. An orthosis was performed by an orthosist on the normal subject. The results revealed that the peak compressive stress (1.6MPa), in the AFO model occurred in the heel regions of the AFO and the maximum tensile stress (0.8 MPa) occurred in the neck region of the AFO during toe-of& Parametric analyses revealed that the model was sensitive to the elastic modulus of the AFO and of the soft tissue, but was relatively insensitive to the ligament stiffness [5].

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